DESIGN OF A FLEXIBLE, SHIPPING WATER TREATMENT SYSTEM FOR DISASTER RELIEF

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ACRONYMS AND ABBREVIATIONS

WHO	World Health Organization
E. coli	Escherichia Coli
NTU	Nephelometric Turbidity Units
MTF	Multiple-tube fermentation
MF	Membrane filter
Cfu	Colony forming unit
DPD	N, N-diethyl-p-phenylenediamine
NGO	Non-governmental organization
PoUWT	Point-of-use water treatment
MF	Microfiltration
UF	Ultrafiltration
RO	Reverse Osmosis
FO	Forward Osmosis
HTH	High-test hypochlorite
UV	Ultraviolet
psi	Pounds per square inch
CH	Calcium Hypochlorite
EPA	Environmental Protection Agency
NSF	National Sanitation Foundation
ANSI	American National Standards Institute
ID	Inside Diameter
Ppm	Parts per million

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ABSTRACT

Domestic water supplies are one of the basic requirements for human life. Without water, life cannot be sustained beyond a few days and the lack of access to adequate water supplies leads to the spread of disease.

Emergency situations, whether created by floods, hurricanes, earthquakes or other natural phenomena, always require urgent attention if It should alleviate the suffering of the affected population in the shortest possible time. The lack of sanitary conditions after the disaster often leads to extremely serious consequences for the population, and causes even more suffering than the disaster itself. Therefore, water and sanitation must be included among the priorities of local authorities.

In some scenarios, bottled water may present the most logical choice, particularly in well-developed countries where there is an abundant supply and a well-developed transport infrastructure. However, the logistical challenges of getting bottled water to a disaster zone can be formidable. In addition, bottled water is very expensive, heavy, produces much packaging waste and it's a short-term response.

Water Purification Systems (WPS) that can be deployed using a smaller transportation and logistical effort are better suited to provide water to disaster victims over a short to medium period of time.

This research project will present the design of a Water Purification System for disaster relief. The main goal of this container-based system is to provide drinkable and clean water to the maximum number of people in emergency situations due to natural disasters.

CHAPTER 1. INTRODUCTION

1.1 The lack of clean water

Domestic water supplies are one of the basic requirements for human life. Without water, life cannot be sustained beyond a few days and the lack of access to adequate water supplies leads to the spread of disease.

Water scarcity refers to the lack of sufficient water resources to meet the demands of water consumption in a region. Even though water on Earth is 71% of the Earth's surface (three quarters of our planet), only about 1% is potable, and its distribution and its difficult accessibility to be used by the human beings lead to water scarcity.

There are three types of water shortages. The first and most important one is the physical shortage, which is defined as the limitation in access to water sources. It affects about 1.2 billion people, almost a fifth of the world’s population. Another 1.6 billion, around a quarter of the world's population, are facing economic water shortages, where countries lack the necessary infrastructure to transport water from rivers and aquifers. The last one is the lack of availability of good quality water, due to the pollution caused by population development, the increase of industry and the absence of treatment of wastewater.

Water scarcity is one of the major challenges of the twenty-first century that many societies around the world are facing. Over the last century, water use and consumption has grown at twice the rate of population growth, and the number of regions with chronic levels of water shortage is rapidly increasing.

Estimates of the volume of water needed for health purposes vary widely. In deriving World Health Organization (WHO) guideline values, it is assumed that the daily per capita consumption of drinking-water is about 2 liters for adults, although actual consumption varies according to climate, activity level and diet. Emergency planners (FEMA and RED CROSS) recommend a water supply of 1 gallon per person per day for drinking and hygiene. It will provide sufficient water for hydration and incorporation into food for most people under most conditions. In addition, adequate domestic water is needed for food preparation, laundry and personal and domestic hygiene, which are also important for health. Water may also be important in income generation and amenity uses.

This quantity includes drinking water and water for foodstuffs preparation. This volume does not account for health and well-being-related demands outside normal domestic use such as water use in health care facilities, food production, economic activity or amenity use.

Table 1: Volumes of water recommended by WHO.

	Volumes (litres/day)		
	Average conditions	Manual labour in high temperatures	Total needs in pregnancy/lactation
Female adults	2.2	4.5	4.8 (pregnancy) 5.5 (lactation)
Male adults	2.9	4.5	-
Children	1.0	4.5	-

1.2 Importance of water in disaster relief

Water, considered by all as a basic element for life, may end up being one of the main limitations and concerns after a disaster. The availability of water in sufficient quantity and quality is critical in the immediate stages to the occurrence of an adverse event to provide care for the sick, human consumption and maintenance of minimum hygiene conditions, support for search and rescue, and the reactivation of productive and commercial activities.

The World Health Organization (WHO) defines a 'disaster' as any occurrence that causes damage, destruction, ecological disruption, loss of human life, human suffering, deterioration of health and health services on a scale sufficient to warrant an extraordinary response from outside the affected community or area. Earthquakes, hurricanes, tornadoes, volcanic eruptions, fire, floods, blizzard, drought, terrorism, chemical spills, nuclear accidents are included among the causes of disasters, and all have significant devastating effects in terms of human injuries and property damages.

Emergency situations, whether created by floods, hurricanes, earthquakes or other natural phenomena, always require urgent attention if It should alleviate the suffering of the affected population in the shortest possible time. There are many needs and wants: food, shelter, clothes, medicines, etc. However, none of them is so important as the need for safe water and basic sanitation conditions. These services go beyond satisfying thirst and allowing food preparation; its importance lies in the protection of public hygiene.

The lack of sanitary conditions after the disaster often leads to extremely serious consequences for the population, and causes even more suffering than the disaster itself. Therefore, water and sanitation must be included among the priorities of local authorities.

Each year, more than 200 million people are affected by droughts, floods, tropical storms, earthquakes, forest fires and other threats. Recent years have shown us that natural hazards can affect anyone and everywhere (Paho, 2006)

Natural hazards, such as earthquakes or hurricanes, can affect large areas and populations, especially in urban areas and marginal areas where the collapse of water and sanitation services limits medical provision in health facilities and deteriorates the environmental conditions and hygiene of the population.

CHAPTER 2. WATER CONTAMINATION

Water is essential for life and all people must have a satisfactory (sufficient quantity, safe and accessible) supply. Improving access to drinking water can provide tangible health benefits. Every effort should be made to ensure that the safety of drinking water is as high as possible. The rules on drinking water may differ, in nature and form, from one country or region to another. There is no single method that can be universally applied. In this project, I am going to use the standards defined by the World Health Organization (WHO), which is an international organization whose role is to direct and coordinate international health within the United Nations' system.

Most health problems related to water are due to contamination by microorganisms (bacteria, viruses, protozoa or other organisms). However, there are several serious health problems that can occur because of the chemical contamination of drinking water.

The greatest health risk associated with water quality in emergency disasters is the transmission of fecal microorganisms due to deterioration of basic sanitation, poor hygiene and poor protection of the source of water supply. The most frequent diseases observed due to water pollution are hepatitis, fever Typhoid, cholera, bacillary and amoeba dysentery.

Access to safe and sufficient water is of vital importance for the protection of health, which makes it necessary to add chemical compounds for the treatment of water as quickly as possible, in order to reduce or eliminate pathogen microorganisms.

2.1 Natural disasters effects on water

Services such as water supply and sewerage are vulnerable to disasters; Installations may be damaged, pipes may be broken and operations may be interrupted by power outages. After disasters, water becomes the most important asset for the affected population and the scarcity or pollution of this resource can have very serious consequences for public health.

Furthermore, water is one of the main means of disease transmission. Therefore, by providing adequate amounts of water to affected populations, the authorities must ensure their safety. In order to protect public hygiene, the authorities should also ensure adequate sanitation, waste disposal, food hygiene and prevention of vector reproduction.

Most of the most common diseases found in traumatized communities after a disaster are related to the consumption of contaminated water. Contamination can be by microorganisms or by natural or man-made chemicals.

According to WHO (2011), emergencies have three relevant effects on people:

• They force people to move to other places where water quality may be different from that which they normally consume and for which they do not possess immunity;

• They compel people to live in poor conditions, such as in tents or temporary buildings, which makes it difficult for them to maintain good hygiene practices, and

• They affect their diet, generally reduce their nutritional value, and make them more vulnerable to disease.

2.1.1 Earthquakes

The movements of the earth's crust, the main source of earthquakes, generate deformations in the interior rocks of the earth and accumulate energy that is suddenly released in the form of waves that shake the surface. They represent one of the most serious threats, due to its huge destructive potential, its wide area of affectation and, in addition, the impossibility of being able to predict its appearance. Contamination of the environment and the drinking water sources with the various chemicals from the demolished and damaged factories cause significant disasters both for the public health and the deterioration of the environment.

Among the consequences that earthquakes can have on drinking water and sewerage systems are:

• Total or partial destruction of the catchment, conduction, treatment, storage and distribution structures.

• Breakage of conduit and distribution pipes, damage to joints between pipes or tanks, resulting in loss of water.

• Interruption of electric fluid, communications and access routes.

• Modification of the quality of raw water due to landslides.

• Decrease in the flow of underground and surface catchments.

• Change of water springs site

• Inland flood damage from tsunami impact.

• Introduction of sea water in coastal aquifers.

2.1.2 Volcanic eruptions

Volcanic eruptions happen when lava and gas are discharged from a volcanic vent. The volume and magnitude of the eruption will vary depending on the amount of gas, the viscosity of the magma and the permeability of the ducts and chimneys. The frequency of these phenomena is very variable, since some volcanoes have continuous eruptions whereas others erupt in intervals of thousands of years.

The main effects of volcanic eruptions in drinking water and sanitation are:

- Aquifers can be lost and changes in water quality can occur due to volcanic contaminants (sulfur, sulfur dioxide, sulfuric and hydrochloric acid, fluorine, methane, and mercury).

- Structures and equipment (e.g. fire hydrants) may be crushed, destroyed or buried.
- Fires
- Clogged air filters can cause engine failure
- Other components of the water system can also be damaged due to dense sedimentation (ash and sludge).

2.1.3 Hurricanes

The hurricane originates when the hot and humid air that comes from the ocean interacts with the cold air; these air currents rotate and move at a speed between 10 and 50 km/h with a totally erratic trajectory.

The main effects of hurricanes in drinking water and sanitation are:

- Debris carried by air and wind causes physical damage to structures, especially on roofs, doors and windows.
- Generally, trees and telegraph poles ripped off pipes.
- Outlets for water collection and piping can become clogged due to debris and sediment.
- Heavy rains cause flooding and damage (especially in electrical equipment).
- Coastal areas are subject to severe erosion.
- Access paths may be blocked.

2.1.4 Flooding

Flooding occurs because of excessive rainfall or abnormal sea level rise, as well as the breakage of dams and dams. The damage from floods is caused by waves and streams that carry waste, which can damage the banks of the rivers and collapse the foundations. Severe contamination of water resources can occur: bacteriological (by wastewater), chemical and physical (by sediment). When a large river floods, many pollutants, such as farm waste, detergents, chemicals from processing plants, and fertilizers from crops, are swept downstream and deposited on land.

In addition, water treatment plants stop working as they are flooded.

2.2 Key water quality indicators

The most frequently measured and recommended parameters for microbial safety are: thermotolerant coliforms or Escherichia coli (absence), chlorine residual (if chlorination is practiced), pH and turbidity. These parameters establish the hygienic state of water and thus, the risk of waterborne disease and the possible transmission of pathogens.

- **Escherichia coli (E. coli)** is a bacterium commonly found in the intestines of humans and warm-blooded animals. It is a thermotolerant coliform, the group of total coliforms that are capable of fermenting lactose at 44-45ºC. Most strains of E. coli are harmless. However, some of them, such as the one that produces the Shiga toxin, can cause serious illness through food or water consumption. E. coli is present in very large concentrations in human and animal feces, and is rarely found in the absence of fecal contamination.
- **Chlorine** is a low-cost treatment option that is used to improve the taste and clarity of water while eliminating many microorganisms such as bacteria and viruses. Proper dosing of chlorine is intended to maintain a residual concentration in the water to provide some protection from post-treatment contamination during storage. However, the amount of residual chlorine should be controlled. Higher amounts of chlorine are required for water that has high turbidity.
- **PH** is one of the most common tests to know part of water quality, although pH usually has no direct impact on consumers. Attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. It is an indicator of the acidity of a substance and it is determined by the number of hydrogen-free (H^+) ions in a substance. The pH of the water may vary between 0 and 14. Solutions with a pH below 7.0 are considered acidic. Solutions with a pH above 7.0 are considered bases or alkalis. For effective disinfection with chlorine, the pH should preferably be less than 8.
- **Turbidity** is a measure of the degree to which water loses its transparency due to the presence of particles in suspension. The more solids in suspension in the water, the dirtier it will look and the higher the turbidity. Microorganisms (bacteria, viruses and protozoa) are typically attached to particulates, so removal of particles by filtration will significantly reduce

microbiological pollution in treated water. A sudden change in turbidity may indicate an additional pollution source (biological, organic or inorganic) or may signal a problem in the water treatment process. It is measured by nephelometric turbidity units (NTU) and can be initially noticed by the naked eye above approximately 4.0 NTU.

According to WHO (2011), the guideline values of the indicators for water safety must be:

Table 2: Standard values for quality indicators according with WHO.

PARAMETER	STANDARD VALUE
E. COLI	Must not be detectable in any 100-ml sample
RESIDUAL CHLORINE	0.2–0.5 mg/l
PH	surface water: 6.5 - 8.5 groundwater: 6 - 8.5
TURBIDITY	1 NTU or lower

2.3 Measurements

There are several methods to measure the different indicators related to water safety. Samples taken from water sources can be taken to the laboratory, or measured directly in the field. As we are talking about emergency situations, the measures will be collected and evaluated on site with field test kits, allowing a faster evaluation and following decontamination.

2.3.1 Escherichia coli

The concentration of Escherichia coli (or thermotolerant coliforms) is usually measured in 100 ml water samples. There are two main methods to detect the existence or absence of coliforms in drinking water: Multiple-tube fermentation (MTF) and Membrane filter (MF) techniques. However, the MTF is not readily adaptable for use in the field.

The membrane filter method gives a direct count of total coliforms and fecal coliforms present in a given sample of water. A measured volume of water is filtered, under vacuum, through a cellulose acetate membrane of uniform pore diameter, usually 0.45 µm. Bacteria are retained on the surface of the membrane which is placed on a suitable selective medium in a sterile container and incubated at an appropriate temperature. If coliforms and/or fecal coliforms are present in the water sample, characteristic colonies form that can be counted directly.

Membrane filtration and colony count techniques assume that each bacterium, a clump of bacteria, or particle with bacteria attached, will give rise to a single visible colony. Each of these clumps or particles is, therefore, a colony forming unit (cfu) and the results are expressed as colony forming units per unit volume.

The most widely used for drinking water analysis are the m-Endo-type media in North America (APHA, AWWA, & WEF, 1998) and the Tergitol-TTC medium in Europe. Coliform bacteria form red colonies with a metallic sheen on an Endo-type medium containing lactose (incubation 24 h at 35 °C for TC) or yellow-orange colonies on Tergitol-TTC media (incubation 24 and 48 h at 37 and 44 °C for TC and FC, respectively).

2.3.2 Residual Chlorine

As it has been stated before, chlorine is a relatively cheap and widely available chemical that, when dissolved in clean water in sufficient quantity, destroys most of the disease-causing organisms without endangering humans. However, chlorine is consumed as organisms are destroyed. If enough chlorine is added, it will remain a little in the water after all organisms are removed; It is called free chlorine.

If water is analyzed and there is still free chlorine in it, it is proven that most of the dangerous organisms have already been removed from the water and, therefore, it is safe to consume. This procedure is known as residual chlorine measurement. Measuring residual chlorine in a water supply is a simple but important method to check if the water supplied is safe to drink.

The most common test is the DPD (N, N-diethyl-p-phenylenediamine) indicator using a comparison kit. This test is the fastest and easiest method to evaluate residual chlorine. In this test, a reagent tablet is added to a sample of water, which stains it red. The color intensity is compared to a standard color chart to determine the concentration of chlorine in the water. The more intense the color, the greater the concentration of chlorine in the water.

2.3.3 Ph

There are three different methods of pH measurement: pH indicator paper, liquid colorimetric indicators and electronic meters.

The use of pH indicator paper is simple and inexpensive, but the method is not very accurate and requires a subjective assessment of color by the user.

Liquid colorimetric indicators change color in accordance with the pH of the water with which they are mixed. The color that develops can then be compared with a printed card, with colored glass standards, or with a set of prepared liquid standards. Colorimetric methods are reasonably simple and accurate to about 0.2 pH units. Their main disadvantage is that standards for comparison or a comparator instrument must be transported to the sampling station. Moreover, physical or chemical characteristics of the water may interfere with the color developed by the indicator and lead to an incorrect measurement. The typical color scale of indicators is shown below.

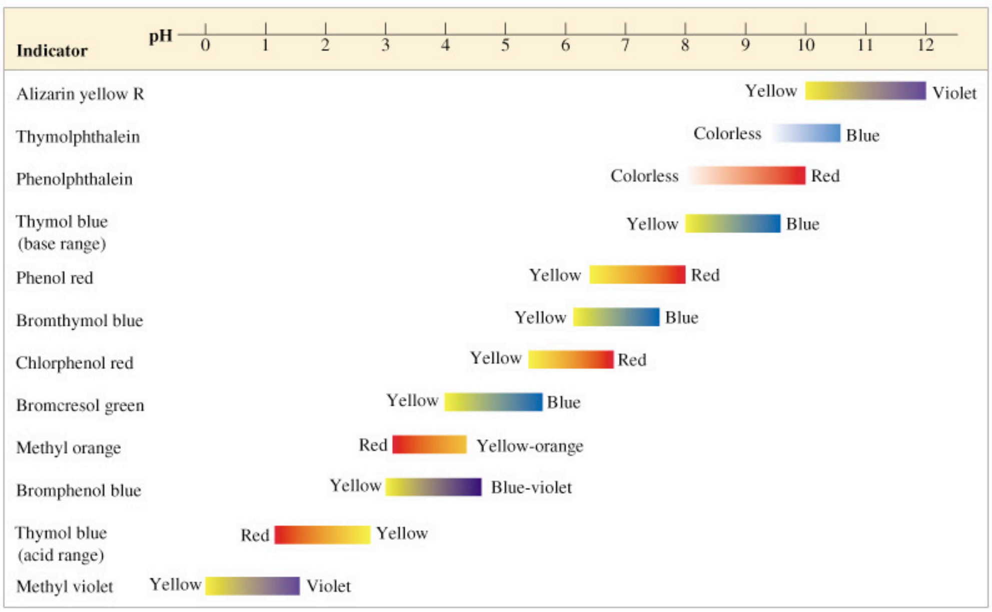


Figure 1: color scale that indicates the pH in the water tested.

Finally, electrometric pH measurement is accurate and free from interferences. Pocket-sized, battery-powered, portable meters that give readings with an accuracy of ± 0.05 pH units are suitable for field use. Larger, more sophisticated models of portable meter can attain an accuracy of ± 0.01 pH units. Care must be taken when handling such equipment. The electrodes used for measurement generally need replacing periodically (e.g. yearly).

The common features of pH meters are a sensing electrode and a reference electrode connected to an electronic circuit that amplifies the voltages produced when the electrodes are immersed in a solution or water sample. The amplified voltage is displayed on a meter graduated in pH units. Sensing and reference electrodes designed for field use are often combined in one element. The electronic circuitry in a portable meter is powered by either disposable or rechargeable batteries, depending on the design of the meter.

Figure 2: image of an electronic pH meter.

2.3.4 Turbidity

Turbidity can be measured using either an electronic turbidity meter or a turbidity tube.

The electronic turbidity meter or nephelometer, measures the intensity of light scattered at 90 degrees when a ray of light passes through a water sample; The higher the intensity of scattered light, the higher the turbidity. Its precision, sensitivity and applicability over a broad turbidity range makes the nephelometric method preferable to visual methods. Nephelometers are relatively unaffected by small differences in design parameters and therefore are specified as the standard instrument for measurement of low turbidities.

Figure 3: image of an electronic turbidity meter or nephelometer.

The turbidity tube uses the correlation between visibility and turbidity to approximate a turbidity level. A marker is placed at the bottom of the turbidity tube until it can no longer be seen from above due to the “cloudiness” of the water. This height from which the marker can no longer be seen correlates to a known turbidity value, which is read from the scale on the side of the tube.

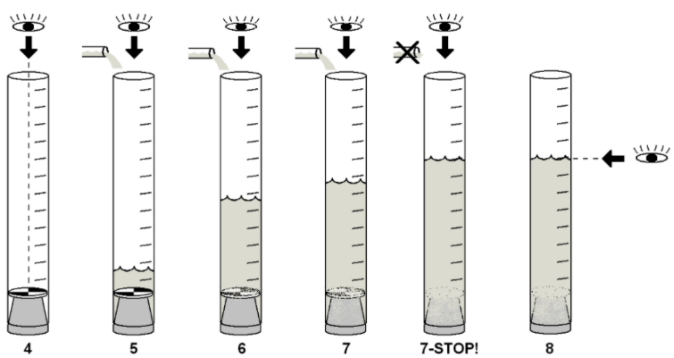


Figure 4: graphic explanation of how to measure the turbidity with a turbidity tube.

Both methods are portable and both have its advantages and disadvantages:

Table 3: Advantages and disadvantages of both the turbiditimeter and the turbidity tube.

	TURBIDITIMETER	TURBIDITY TUBE
ADVANTAGES	• Extremely accurate • Can measure very low turbidity	• Low cost • No consumables • Easy to learn • Suitable for all water sources
DISADVANTAGES	• Expensive • Easily damaged • Requires power source • Requires calibration	• Less accurate. • Can't measure < 5 NTU

Of the available approaches to turbidity testing, a turbidity tube is the most appropriate method to test small community water supplies when funds are limited. The turbidity tube is inexpensive, easy to use, and does not need to be restocked with batteries or testing supplies. A turbidity tube can be understood intuitively, even by non-engineers. Moreover, the use of a turbidity tube conveys more information about what is being measured than does looking at a readout on a digital screen. This provides an opportunity to educate community members about many water quality issues, including source protection and treatment options. Turbidity tubes are also very portable and are designed for use in the field. This is an added benefit; turbidity is more accurately measured on-site as it can change rapidly during transport or storage (WHO, 2011).

Because of its many advantages, a turbidity tube can be employed in a wide range of settings. Several international NGO's, including Oxfam and Doctors Without Borders, use turbidity tubes as part of their water quality testing kits for emergency situations.

2.4 Test kit selection

As it has been stated before, it is necessary to measure water levels of chlorine, pH, turbidity and E. coli. There are two available test kits that meet our criteria to monitor the quality of drinking water at the source: delAgua Kit and the Wagtech Kit.

After extended study, delAgua Kit is the best match with regards to price, available tests, durability and portability (it has complete portability for testing in remote areas).

The kit will perform the following tests (delAgua Water Testing Ltd, 2015):

Figure 5: turbidity tube

Turbidity Test: A measure of the amount of suspended matter in a water supply is taken by a turbidity meter that covers the range 5 to 2,000 NTU.

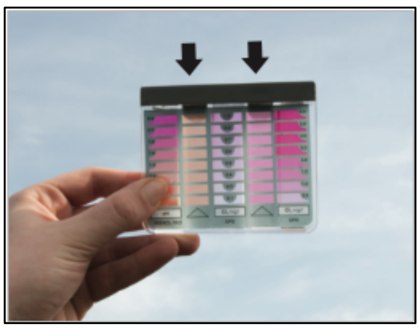


Figure 6: comparator block

Chlorine & pH Tests: A comparison kit consisting of the comparator block, 250 DPD tablets for the free chlorine measure plus 250 DPD tablets for total residual chlorine measure and 250 Phenol Red tablets for the pH measure. The measures of both pH and chlorine are taken matching the color in the cells with the standard color scales.

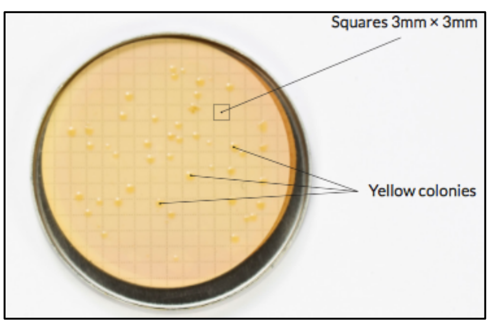


Figure 7: medium growth membrane

Thermotolerant (fecal) Coliform Count: The kit includes a portable, battery-powered incubator capable of making five cycles of incubation. As it has been explained before, after the water sample passes through a 0.45-micron membrane filter, present bacteria are caught. The filter is placed in a liquid medium growth (membrane Lauryl Sulfate Broth (MLSB)) and incubated at 44ºC for 16-18 hours. After this time coliforms are recognized by its color change from yellow to red in the medium. Results are expressed as colony-forming units per 100ml sample (CFU/100ml).

Other specifications:

- Complete Kit Weight: 10kg
- Dimensions: 34.4 x 14.6 x 29.7cm
- Test Capacity: 16
- Total items: 32
- Price: $2,000

Figure 8: DelAgua test kit

2.4.1 Tests procedures

The first tests that should be carried out on a drinking water sample are the determination of chlorine residual, pH and turbidity.

The results from these tests will indicate if the water sample is likely to contain living microorganisms and whether it is necessary to carry out analysis for thermotolerant coliform bacteria. It will be necessary to carry out thermotolerant coliform analysis if the results DO NOT meet these criteria:

- Free chlorine residual > 0.2 mg/liter
- Turbidity < 5 NTU

If the results meet the criteria above, it is unlikely that the sample will contain thermotolerant coliform bacteria and therefore, it may not be necessary to carry out the coliform analysis. However, to remove any doubt, the analysis should be carried out.

If results show that no total coliforms or E. coli has been detected, water is free of contamination and can be drunk. Otherwise, water must be treated and disinfected.

CHAPTER 3. CURRENT POINT-OF-USE WATER TREATMENT TECHNOLOGIES

There are two conventional ways of providing potable water to the affected population during emergencies and population migration. The first is to package treated water and transport it to the site. However, due to environmental constraints, this transportation could not provide immediate supply of clean water. While immediate response is needed, conventional treatment plants could not carry out normally as planned and consequently fail to supply in the long run. Another way to have drinking water is the use of point-of-use water treatment (PoUWT) technologies. They have been a promising alternative method to provide access to clean and safe drinking water in emergencies.

The different qualities of water will condition the treatment to which it must be submitted to be apt for human consumption (improved or even drinking water). The ideal situation is to have groundwater, not contaminated, properly protected and captured by techniques that ensure its quality, but this is rarely the case. The most frequent situation is having to use surface and contaminated water or underground water with dubious quality and protection.

The selection of the drinking water treatment method depends on a variety of factors such as the quality of the raw water, the required flow, the available financial resources and various logistical and human resources conditions, such as transport or the availability and level of training of operators. In emergency situations, a system is sought that is capable of effectively and safely treating waters of different grades and levels of contamination (turbidity), which is simple in its handling and assembly, economically acceptable, robust and resistant, transportable and with an adequate production for the given population.

The most used PoUWT technologies in emergencies are assisted sedimentation, filtration, disinfectants, solar disinfection, boiling or advanced oxidation processes, among others.

3.1 Assisted sedimentation

This treatment is used to provide water with the qualities of turbidity, color, content of colloidal substances and organic matter that needs to be consumable. It consists of two parts: coagulation and flocculation, and sedimentation.

The Coagulation-flocculation process accelerates the precipitation of suspended particles which, because of their diameter, less than 0.01 mm, have very low sedimentation rates. It is initiated by adding chemical coagulants such as aluminum sulfate (alum), ferric chloride, ferric sulfate, or natural coagulants that change the behavior of the suspended particles, causing them to be attracted to one another or to the aggregate compound. Thus, the particles come together in small masses called "flocs" in a way that their weight exceeds the weight of the water and can settle faster.

Coagulation occurs during rapid mixing or the agitation process immediately following the addition of the coagulant (flocculation). The effectiveness of coagulation and flocculation is strongly influenced by the pH of the water. The rapidity of settling is greatest when initial mixing is done thoroughly. After a period, which depends on the turbidity of the raw water and the quantity being treated, the sludge at the bottom of the tank needs drawing off and disposing of.

Finally, during sedimentation, the flow of the water is slowed to resemble a calm environment. As the water is calm, the large flocs that have been formed settle to the bottom of the sedimentation basin, sometimes called a clarifier. As the flocs are settling to the bottom, the relatively particle-free water passes over a system of weirs and moves to the filtration process.

One good example of this process is the Procter & Gamble Company (P&G) PuR Purifier of Water™

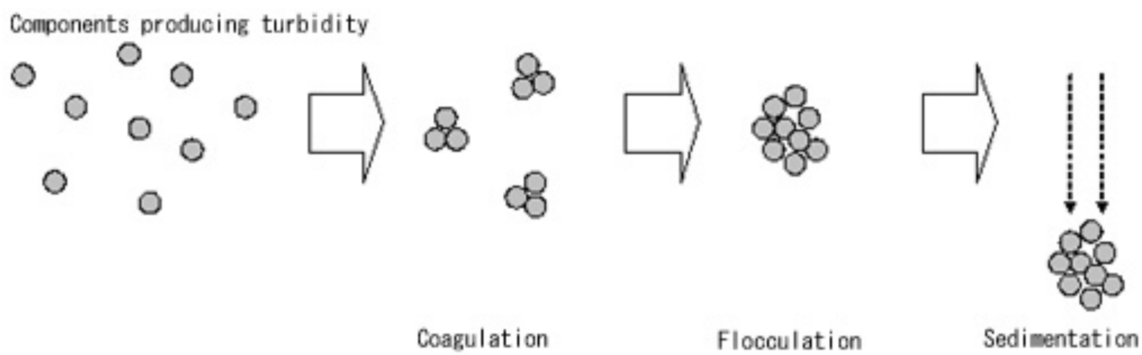


Figure 9: graphic explanation of the assisted sedimentation process.

Disadvantages of this technology are:

- The higher relative cost per liter of water treated compared to other household water treatment options
- The need for multiple steps to use the product, which requires time to teach new users

3.2 Filtration

Filtration is a process that followed by sedimentation, can be used to reduce the turbidity of water carrying large amounts of suspended solids. Filtration is any of various mechanical, physical or biological operations that separate solids from fluids (liquids or gases) by adding a porous medium through which only the fluid can pass.

There are many types of filters that can be used for emergency situations, the main ones are described below.

3.2.1 Ceramic Filtration

Gravity-fed ceramic filters, using either pot- or candle-shaped filter elements, have been used traditionally in many countries to treat drinking water at the household level (Sobsey, 2002). Numerous locally manufactured and commercial ceramic filters are currently available in developing and developed countries. One locally manufactured design is the Potters for Peace filter, which is flowerpot-shaped, holds 8-10 liters of water, and sits inside a plastic or ceramic receptacle. The filters are produced locally, where they are formed, fired, and impregnated with colloidal silver. The impregnated filters remove most bacteria and protozoa from source water. The colloidal silver also prevents growth of bacteria within the filter itself. Many commercial filters are candle-style filters. Most ceramic filter systems are based on a filter/receptacle model. Families fill the top receptacle or the ceramic filter itself with water, which flows through the ceramic filter or filters into a storage receptacle. The treated water is then accessed via a spigot. The effectiveness of ceramic filters at removing microbial pathogens depends on the production quality of the ceramic filter.

Disadvantages of this method are:

- Higher quality ceramic filters are effective at removing most protozoa and bacteria, but not viruses
- Because of the lack of residual protection, it is important that users be trained to properly care for and maintain the ceramic filter and receptacle.
- The method is not very fast (20 liters in a few hours).

- Ceramic filters are not readily available on the market
- They are fragile and should be cleaned from time to time

3.2.2 Membrane Filtration

A membrane is a thin layer of semi-permeable material that separates substances when a driving force is applied across the membrane. Membrane processes are increasingly used for removal of bacteria, microorganisms, particulates, and natural organic material, which can impart color, tastes, and odors to water and react with disinfectants to form disinfection byproducts.

The volume of research and development of membranes has expanded considerably over the last 20 years with new ideas and more development directions have emerged. Membrane surface modification emerged as a new way to enhance the membrane performance in terms of improved permeate flux and lower fouling rate, which is a result of weaker interaction of fouling materials with modified membrane surfaces. Such modification techniques include plasma treatment, physical coating of hydrophilic layer on membrane surface, use of nanoparticles for surface modification, and chemical reactions on membrane surfaces. Another new application is the development of hybrid materials which combines photo-catalysis with membrane technology.

Applications of membrane filtration have expanded rapidly for both particulate/microbial removal and for a removal of a host of particulate and dissolved contaminants. Each membrane has specific characteristics. This resulted in an increase in competition between companies producing membranes and, in turn; membrane technology is now becoming an economically feasible process. Membrane filtration offers a rather simple operation and a low cost in comparison to conventional methods. There is no doubt that this technique has a large potential application as more researchers try to design portable water purification systems, which are practical and appropriate in times of natural disasters.

Common membranes used are microfiltration (MF); followed with ultrafiltration (UF), reverse osmosis (RO) and forward osmosis (FO).

The main disadvantages of membrane filtration are:

- Membrane fouling: solute or particles deposit onto a membrane surface or into membrane pores in a way that degrades the membrane's performance
- Production of polluted water (from backwashing)
- Membranes must be replaced on a regular basis
- High energy use that may not be available in disaster situations

3.2.3 Sand Filtration

Relatively fine sand is used and a slow rate of filtration to remove impurities by sedimentation, adsorption, sieving, and chemical and biological processes. Low sand filters usually consist of tanks containing sand (effective size range 0.15–0.3 mm) to a depth of between 0.5 and 1.5 m. The raw water flows downwards, and turbidity and microorganisms are removed primarily in the top few centimeters of the sand. A biological layer, known as the "schmutzdecke", develops on the surface of the filter and can be effective in removing microorganisms. Treated water is collected in underdrains or pipework at the bottom of the filter. The top few centimeters of sand containing the accumulated solids are removed and replaced periodically. Slow sand filters operate at a water flow rate of between 0.1 and 0.3 $m^3/m^2{\cdot}h$.

Slow sand filters are more suitable for low-turbidity water or water that has been pre-filtered. They are used to remove algae and microorganisms, including protozoa, and, if preceded by micro straining or coarse filtration, to reduce turbidity (including adsorbed chemicals). Slow sand filtration is effective for the removal of some organics, including certain pesticides and ammonia.

According to Centers for Disease Control and Prevention (2014), slow sand filter lab effectiveness studies with a mature bio layer have shown 99.98% protozoan, 90-99% bacterial, and variable viral reduction. Field effectiveness studies have documented *E. coli* removal rates of 80-98%. However, some disadvantages of this method are:

- Not as effective against viruses
- No chlorine residual protection – can lead to recontamination

- Routine cleaning can harm the bio layer and decrease effectiveness
- High initial cost and high weight

3.3 Boiling

Boiling water will kill bacteria as well as other disease-causing microorganisms like Giardia lamblia and Cryptosporidium parvum, which are commonly found in rivers and lakes. Although boiling time recommendations vary significantly, from 0-20 minutes, waterborne microbes that are pathogenic to humans are killed or inactivated even before the water reaches 212ºF, pasteurization is effective at 160 ºF. The World Health Organization (WHO) thus recommends that water be heated until it reaches the boiling point (WHO, 2011).

Water should be stored in the same container in which it was boiled, handled carefully, and consumed within 24 hours to minimize recontamination. Boiling is effective at inactivating all waterborne bacteria, viruses, and protozoa that cause diarrheal disease (Clasen, 2008c). However, it has some disadvantages:

- Does not remove turbidity/cloudiness
- Does not provide residual chemical disinfectant, such as chlorine, to protect against contamination
- High-energy costs
- It is a time-consuming job
- Fuelwood consumption leads to deforestation
- Change in the taste of water caused by the release of air from the water

3.4 Chlorination

The most common method of disinfection in emergencies is chlorination. Chlorine gas is most commonly used in urban water-treatment works, but this requires careful storage and handling by well-trained staff, as well as dosing equipment. For emergency water-treatment installations, chlorine compounds in solid or liquid form are most often used, as these are simple to store and handle, and may be dosed using simple equipment, such as a spoon or bucket.

The chlorine compound most commonly used for water disinfection in emergencies is calcium hypochlorite, in powder or granular form. One form of calcium hypochlorite that is frequently used is high-test hypochlorite (HTH).

Free residual chlorine levels of more than 0.3mg/l for more than 30 minutes are required to kill bacteria and most viruses. Important advantages of chlorine disinfection are that it is simple to dose and to measure, and that it leaves a residual disinfection capacity in the treated water, safeguarding against contamination in the future. This is particularly important when sanitation is inadequate.

Chlorination is less effective in turbid water. If the raw water has a turbidity over 20 NTUs, then some form of pretreatment should be carried out. Ideally the turbidity should be less than 5 NTUs. Also, contact time or free chlorine residual should be increased in water with a high pH. It is effective for killing most bacteria and viruses. Its disadvantages are:

- Lower disinfection effectiveness in turbid waters contaminated with organic and some inorganic compounds
- Relatively low protection against parasitic cysts
- Necessity of ensuring quality control of the solution

3.5 Solar disinfection

It uses solar energy to destroy pathogenic microorganisms causing water borne diseases and there- with it improves the quality of drinking water. Pathogenic microorganisms are vulnerable to two effects of the sunlight: radiation in the spectrum of UVA light (wavelength 320-400nm) and heat (increased water temperature).

A synergy of these two effects occurs, as their combined effect is much greater than the sum of the single effects. This means that the mortality of the microorganisms increases when they are exposed to both temperature and UVA light at the same time.

Solar disinfection is ideal to disinfect small quantities of water of low turbidity.

Transparent containers are filled with water and exposed to full sunlight for 5 hours (or two consecutive days under a completely cloudy sky). If the water reaches a temperature of at least 50ºC, a period of one hour exposure is enough.

- Requires weather conditions with a minimum amount of sunlight
- Only suitable for turbid water less than 30 NTU; need for pretreatment (filtration or flocculation) of waters of higher turbidity
- Not suitable for large volumes of water
- The length of time required to treat the water
- The large supply of intact, clean, suitable plastic bottles required

3.6 Advanced oxidation processes (AOPs)

Processes aimed at generating hydroxyl radicals are known collectively as advanced oxidation processes and can be effective in the destruction of chemicals that are difficult to treat using other methods, as well as viruses and bacteria.

Hydrogen peroxide with UV is also a source of hydroxyl radicals. Chemicals can react either directly with molecular ozone or with the hydroxyl radical (HO·), which is a product of the decomposition of ozone in the water and is an exceedingly powerful indiscriminate oxidant that reacts readily with a wide range of organic chemicals. The formation of hydroxyl radicals can be encouraged by using ozone at high pH.

Examples of advanced oxidation processes are ozonation, hydrogen peroxide addition, chlorination, or UV irradiation. Usually, one type of oxidation method is typically insufficient for micro pollutant removal, while a combination of oxidation methods with each other or with other advanced treatment techniques leads to significant improvement up to complete removal.

Although this method is very efficient to treat almost all organic pollutants and remove some toxic metals, it has some disadvantages:

- High operating costs due to chemicals and high energy inputs
- Formation of oxidation intermediates potentially toxic
- Emerging technologies (still a lot of research is required)

CHAPTER 4. CURRENT WATER PURIFICATION SYSTEMS FOR LARGE GROUPS

4.1 Outback plus 4-stage gravity powered water filtration system

The Outback PLUS is a gravity-powered system that purifies water from almost any fresh or moving water source. Rugged and durable, it was designed to be used not only during emergencies, but for daily use when municipal systems are compromised or in undeveloped areas where systems are not available. The OB-25NF has 4 stages that effectively remove bacteria at > 99.9999%, cysts at > 99.99%, virus at > 99.99%, organic contaminates, pesticides, herbicides, chlorine and more. Operation is simple; just pour water into the upper chamber through the pre-filter net and wait for the water to filter down to the lower chamber. With FEMA, Red Cross and other agencies recommending an emergency supply of at least 1 gallon of potable water per person per day, the OB-25NF will easily purify water for an entire family for the duration of an emergency (ESP Water Products, 2017).

Specifications

- 4 stage Emergency Filter System: pre-filter, filter sleeve, primary filter and secondary filter
- Production Rate: 24-48 Gallons Per Day
- 2-gallon upper chamber, 5-gallon lower chamber
- Removes virus, bacteria, cysts, organic contaminates, pesticides, herbicides, chlorine
- Assembled Dimensions: 12" x 12" x 24"
- Assembled Weight: 5.94 lbs
- Price: $212

Figure 10: Outback filter system

4.2 Portable Aqua Unit for Lifesaving (PAUL)

In February 2012, an initiative was launched at the annual South-East Lions Convention to provide PAUL units for use in disasters.

PAUL is a water filter that ensures a fast supply of drinking water either in disaster areas or in rural areas. The device filters pathogens out of the water, making it drinkable and offering effective protection against cholera, typhus and other infectious diseases. It can be carried by only one person as a backpack to remote areas since it weighs only 20 kg. PAUL weighs 20kg and can be carried to location on an individual's back or dropped by helicopter or parachute. Once in place PAUL can produce 1,200 liters of clean drinking water a day from contaminated water, without using chemicals or electricity. The contaminated water is simply poured in the top and after 10 to 15 minutes clean, safe drinking water becomes available, with a whole tank taking approximately 3 hours to produce.

The filter is easy to use. Pour the dirty water in at the top, and draw off clean drinking water from the tap after only a few minutes. The device works reliably for years without any energy consumption, chemicals or additives. It is extremely robust and has no moving parts. The manual consists of simple pictograms that can also be understood by illiterates. Anyone can therefore use the device.

To clean the water, PAUL has a membrane filter with pore diameters of about 0.04 microns that remove over 99.99% of bacteria and pathogens. A single PAUL unit will operate for months without maintenance in a disaster zone and has an expected life of 10 years.

Specifications

- Production rate: 317 gallons per day
- Membrane area of 9.5 m^2
- Weight: 20 kg
- Dimensions: 1.2 x 0.4 x 0.4 m
- No energy or chemicals needed
- No maintenance
- Ultra-low pressure: 0 to 0.08 bar
- Price: 1279 $

Figure 11: Paul filter system

4.3 The Nomad

Noah Water Systems, Inc. manufactures and sells **The Nomad™**, a portable water purification system capable of producing 25 gallons / 95 liters per minute or 36,000 gallons / 136,800 liters per day of safe drinking water from fresh water sources: wells, lakes, ponds, rivers or flood waters.

It consists of an Ultraviolet water treatment system that destroys five major categories of contaminants with a UV lamp. The UV lamp operates using a low-pressure mercury vapor to produce the UV energy necessary to kill the microorganisms that can live in water. In addition, it has a filtration system to remove suspended solids as well as harmful chemicals and unpleasant taste/odor problems. The filter consists of a 0.5-micron carbon block filter.

This unit comes complete with its own generator, pump and water inlet pickup. All hoses and connections use the quick-connect system for easy use and fast assembly. The unit is shipped in 2 custom ATA Specification 300-Category 1 Flight Cases complete with loading skids. The Nomad™ is a completely self-contained / self-sufficient water purification unit, making it the ideal choice to provide remote water service to larger groups.

Operating the unit is easy and effective, with assembly limited to quick-connect hose. The UV light source should be replaced after 9,200 hours of operation. The life of the Sediment and Carbon filters is completely determined by the amount of dirt, sediment and particulates in the source water. When the filters begin to reach the end of their useful life, the water out-flow will gradually diminish, indicating the need for filter replacement. Noah Water Systems carries a complete supply of replacement filters.

Specifications

- Production rate: 25 gallons/minute → 36,000 gallons/day
- 4-stage purification process
- Removes viruses, bacteria, fungi, algae and protozoa
- Case dimensions: 34x29x38 inches

- Weight: 600 lbs. / 272 kg
- No chemicals needed
- Honda gasoline generator and pump
- Price: $18,100

Figure 12: The Nomad water purification system

4.4 The Trekker

Noah Water Systems, Inc. manufactures and sells **The Trekker™**, a portable water purification system capable of producing 1 gallon/3.8 liters per minute of safe drinking water from fresh water sources: wells, lakes, ponds, rivers or flood waters.

The unit is powered by a 12-volt DC current that can be supplied from any source: auto, truck, generator, airplane, boat, etc., making The Trekker™ an ideal choice in remote areas where electrical service is either impractical or unavailable.

The water purification system is the same as the "The Nomad": a carbon block filter system and a UV lamp.

Specifications

- Production rate: 1 gallon/minute → 1,440 gallons/day
- 4-stage purification process
- Removes viruses, bacteria, fungi, algae and protozoa
- Case dimensions: 17x21x9 inches
- Weight: 26.5 lbs. / 12 kg
- No chemicals needed
- Total portability
- Price: $1,195

Figure 13: The Trekker water purification system

CHAPTER 5. DESIGN GENERAL DATA

After studying the situation of the current technologies and devices that are used in today's emergency situations, the next step is to design the flexible, shipping container-based system of the project.

As it has been stated before, in situations of disaster relief, time is essential to help the maximum people in the least possible time, preventing or lowering the spread of diseases through contaminated water. Thus, we are looking for:

- Maximum capacity
- Cost effective, not minimum cost per device, but minimum cost per liter/gallon
- Easy to use
- Portable and easy to transport
- Quickest access to clean water: short cycle/ high flow rate
- Designed for compact storage
- High performance: kills bacteria and virus and removes protozoa, cysts and particulate

5.1 Water treatment technology

After the study of several methods, chlorination followed by membrane filtration has been selected.

Chlorination is a cheap, fast and effective way to produce drinkable water. However, its effectiveness decreases with turbidity, offers relatively low protection against parasitic cysts and its residual quantities must be controlled. In addition, as fast access to water is needed in a situation of disaster relief, we will use the shock chlorination technique.

Chlorination is employed primarily for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal of some chemicals – for example, the decomposition of easily oxidized pesticides, the oxidation of dissolved species to form insoluble products that can be removed by subsequent filtration; and the oxidation of dissolved species to more easily removable forms.

Super chlorination is the addition of a large dose of chlorine to effect rapid disinfection and chemical reaction, followed by the reduction of excess free chlorine residual. Removing excess chlorine is important to prevent taste problems. It is used mainly when the bacterial load is variable or the detention time in a tank is not enough.

That is where the membrane filtration fits. The turbidity would be highly decreased, and viruses, bacteria and protozoa would be removed as well. Furthermore, the filter of the final step will reduce the free chlorine to meet the standards of WHO guidelines for drinking water.

In treatment processes where super chlorination is used, it is mandatory to remove excess chlorine and possible trihalomethanes with activated carbon filtration. Activated charcoal is known for its ability to eliminate the residual free chlorine we need in the light of possible and future contamination. Furthermore, the “chemical taste” that is left in the water after the chlorination will also be removed by the activated carbon.

This filtration, or rather, adsorption with activated charcoal filters, found in many compact plants, has the function of reducing or removing volatile organic compounds, pesticides and herbicides, compounds with trihalomethanes, radon, solvents and other products.

Adsorption is a process by which molecules of impurities adhere to the surface of activated carbon. Adhesion works by electro-chemical attraction.

Activated charcoal is prepared from various materials, such as wood, walnut shells or preferably coconut shell. Coal "activates" when heated to high temperatures (800 to 1000 ° C) in the absence of oxygen and as a result creates millions of microscopic pores on its surface. This enormous amount of surface area provides great opportunities for the adsorption process to take place, which is a strong attraction for other carbon-based (organic) molecules, and is excellent for firmly retaining molecules that cause odors or flavors.

We would use the most commonly used chlorine compound for water disinfection: the calcium hypochlorite [Ca(OCl)2] in powder or granular form. This is because these forms of free chlorine are convenient, relatively safe to handle, inexpensive and easy to dose.

Calcium hypochlorite must be dissolved in water, then mixed with the main supply. Chlorine, in the form of calcium hypochlorite, dissolves in water to form hypochlorous acid (HOCl) and hypochlorite ion (OCl-).

Membrane filtration offers a rather simple operation and a low cost in comparison to conventional methods. Membrane processes have excellent separation capabilities, high purifying performance and are highly versatile.

As it has been stated before, the membrane processes of most significance in water treatment are reverse osmosis(RO), ultrafiltration (UF), microfiltration (MF) and forward osmosis (FO).

Most MF and UF membranes can successfully eliminate microorganisms of the size range between 0.1–5 µm such as bacteria, viruses and protozoa, and require minimum pressure to operate the system. Meanwhile RO membranes are usually excellent in getting rid of high molecular compounds and dissolved inorganic pollutants. However, the operating pressure is a lot higher than in UF and MF.

Since the previous chlorination process is effective in killing most viruses and bacteria, both MF and UF filters would work, avoiding the need of applying high pressures.

According to WHO (2011), filter medium pore size must be rated at 1 micron (absolute) or less for filtration of clear unsafe water. 1-micron or less filter pore size will remove Giardia lamblia, Cryptosporidium and other protozoa. Thus, the carbon filter will be 1-micron to be a certified cyst removal filter, being able to remove protozoa such as Cryptosporidium and Giardia which are not killed by the chlorine. We could choose a smaller pore size to sieve out even smaller particle, but with the previous shock chlorination there is no need. Furthermore, the smaller the pore size the lower the flow rate, and we want to speed up the filtration process.

5.2 Components

The system is made up of several components supplied by different manufacturers:

- A tank where water will be poured and disinfected with chlorination
- Calcium hypochlorite in tablets of granular form
- A replaceable carbon block filter, located in the point of water distribution

- Flat hoses set
- Filling + Dispensing pumps
- Point of distribution (filter housing + drinking hoses)

5.2.1 Carbon block filter

The most common natural substances used as a base material to make activated carbon are lignite, bituminous and anthracite coal and peat, wood and coconut shell.

Coconut-shell based activated carbons are predominantly microporous and are the least dusty, thus, they are very efficient when it comes to organic chemical adsorption. Compared to other types of activated carbon, coconut-shell based activated carbon filters have the highest hardness, which makes them ideal for water purification.

Apart from these unique properties, coconut shells are also an eco-friendly and a renewable resource for water purification.

After considering several products and manufacturers, we have chosen the block filter *CBMXR-BL-CB* from Dormont.

Table 4: Specifications of the activated block filter.

Materials	Carbon - Coconut Shell End Caps - Polypropylene Inner Wrap - Polypropylene Netting - Polypropylene Gaskets - Neoprene	
Capacity	150,000 gallons	
Certifications	NSF/ANSI Standard 42	
Filter Dimensions	20" L x 4-1/2" ID	
Flow Rate	4 Gallons Per Minute	
Micron Rating	1	
Reduction Claims	Chlorine Taste, Odor, Sediment, Cysts	
Chlorine capacity	17,000 at 1 gpm	

Max differential pressure	100 PSI	
Temperature rates	40°F - 180°F	
Weight	3 kg	
Price	$50	

5.2.2 Water Tank

The materials forming the tank must be lightweight, waterproof, tough and resistant to UV rays. We want it to be easy to move, store and a space-saving design. Thus, the structure will be semi-rigid.

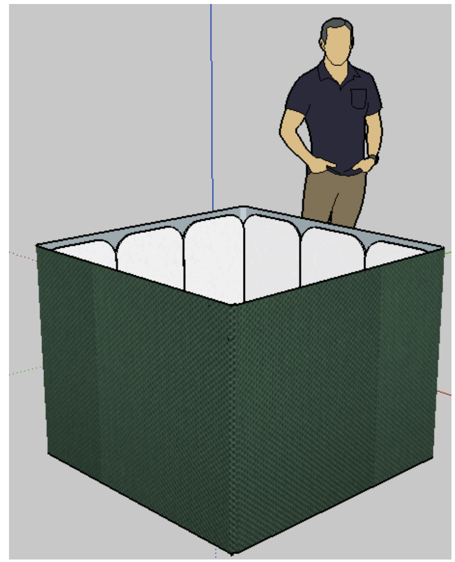
The parts of the tank are:

- Shell
- Support panel set
- Inner liner

For the tank shell, the PVC coated polyester is a very good fit. It is frequently used for flexible fabric structures. It is made up of a polyester scrim, a bonding or adhesive agent, and an exterior PVC coating. This material fabric is tough, flexible and good resistant to abrasion, weathering and ozone.

The support and base of the tank will be made from corrugated plastic panel set that would make the structure of the tank, providing stability. Every tank will consist of 12 panels (3 panels per lateral face).

Table 5: Specifications of the tank

Materials	Panels – corrugated plastic Shell – PVC coated polyester	
Measures	Panels – 15”x35”x0.47” Shell – 45”x45”x35”	
Capacity	300 gallons	
Weight	11.4 kg	
Price	$1756	

One of the best materials for the inner liner is the LDPE (low density Polyethylene). The form fit design allows for a consistently complete fill and dispense of water because the liner has no pleats, folds or other traps to hinder material flow. The liner also allows the outer container to be reused instantly and eliminates the need for costly cleaning operations. LDPE is resistant to impact (doesn’t break easily), moisture (water proof), and chemicals (can stand up to many hazardous materials).

Table 6: Specifications of the liner.

Materials	Liner - C43 coextruded low density polyethylene (LDPE) 1.5” threaded fill fitment - BSP 1.5” threaded dispense fitment – BSP	
Measures	41”x41”x42”; 3.2 mil thick	
Capacity	300 gallons	
Weight	4.08 kg	
Price	$29.19	

5.2.3 Calcium hypochlorite

As it has been stated before, the disinfectant will be calcium hypochlorite (CH) in tablets of granular form. We will use CH with 70% by weight active chlorine.

Superchlorination is accomplished by adding 4-6 ppm of new chlorine to the water. Knowing the liters of water in the tank and the chlorine content of the tablet, we can calculate the grams of tablet we need to add to the tank:

$W = C \times V / S$

Where:

- W: weight of powder required [mg]
- C: concentration of chlorine required [ppm]
- V: volume of the tank [L]
- S: strength of powder [%/100]

$W = 6 \times 1135L / 0.70 = 9728$ mg = ~ **10 grams**

Calcium hypochlorite in a granular form is mixed with water and poured into the tank as the tank is being filled. This produces a mixture of 4 to 6 parts per million of residual chlorine considered "super chlorination."

A “pre-dissolve” step must be done to make sure that all the solid calcium hypochlorite is in solution prior to adding it to the water in the liner. A mixing container is supplied. The solutions should be added to the tank before the tank is half-full.

The 1.0-micron filter will remove residual chlorine down to approximately 0.3 to 0.5 ppm, the WHO and EPA recommended residual chlorine level.

The disinfectant will be provided in tablets of 10 grams, ready to use. The recommended contact time before start dispensing is 60 minutes.

Table 7: Specifications of the calcium hypochlorite tablets.

Materials	Calcium hypochlorite 70% active chlorine Bottle - very strong HDPE bottle with tamper proof and child resistant cap	
Dose	10g tablets (100 tablets)	
Weight	1 kg	
Price	$13	

5.2.4 Pump

Except in cases where water can be transported by gravity (springs), in most cases it will be necessary to use pumping elements (hand pumps, motor pumps or submerged pumps) to extract water from wells or boreholes (deeper wells) and / or raise it to deposits to distribute. There are several types of pumps (FARMAMUNDI, 2001):

- Hand pumps: they are basically used for the collection of groundwater, either in wells or boreholes. Flow rates of hand pumps are 7-13 gallons per minute. They are low tech pumps which may already be available locally.
- Motor pumps: they are used to capture shallow groundwater (<7m) from wells and surface waters. A wide variety of models, both gasoline and diesel, are available in the market. The flows they deliver reach 600 liters / minute and the height at which they can raise the water reaches 40 meters, although in general they have the drawback that the distance between the suction point and the motor pump can hardly exceed 7 Meters; Therefore, they do not serve to extract the water from boreholes or deep wells.
- Submerged pumps: They are ideal for extracting water from drillings and deep wells due to their high lifting capacity. Of reduced volume, only must be submerged in the water, secured by a cable or chain to which the electrical cable and the drainage hose will be attached. Some models allow their use even with high suspended matter and, although their flow is somewhat smaller than the flow of the motor pumps, they can raise volumes of 300 liters / minute. They work with electrical energy so they are usually coupled to a generator, located

on the surface.

The best option for our device is the hand pump, as it is human powered and no electricity or battery is needed (lees footprint), it is useful collecting groundwater, it is not as heavy as the other ones and it is also cheaper.

The ‘Amazon Warrior pump’ from Jabsco is a very good option. Its specifications are shown below:

Table 8: Specifications of the hand pump.

Materials	Housing - Propylene Nozzle - Nylon Filled Plastic Handle – Stainless steel	
Maximum output	30 gpm	
Dimensions	365mm L, 200mm W, 260mm H, with 450mm handle	
Weight	4.82 kg	
Fitting size	for 38mm (1½”) bore hose	
Price	$442	

5.2.5 Flat hoses set

We need four flat hoses with the following aims:

1. lift water from a source
2. fill the tank
3. transport water from the tank to the dispense pump
4. transport water from the pump to the filter

They will be made from the same material as the tank shell, vinyl coated polyester, a very resistant material.

The fitting size of the cams must be the same as the pump’s ports which is 1-1/2”. The following hose has been selected:

Table 9: Specifications of the flat hose.

Materials	Tube – vinyl coated polyester Cams – aluminum	
Length	25 feet	
Color	Red	
Fitting size	1-1/2”	
Max pressure	80 psi	
Price	$56.85	
Weight	2.49 kg	

The suction pump will be different. To prevent large solids from entering the filling pump, it will have a suction strainer attached and it will be reinforced to improve its strength:

Table 10: Specifications of the suction hose.

Materials	Hose - PVC reinforced Cam-lock fitting – stainless steel Strainer - zinc	
Length	20 feet	
Color	Grey	
Fitting size	1-1/2”	
Max pressure	380 psi	
Price	$43	
Weight	3.4 kg	

5.2.6 Point of distribution

The point of distribution consists of:

- Filter housing
- Drinking hoses

The filter housing will store the activated carbon filter. The canister that has been selected is a convertible filter housing, manufactured from polypropylene with a UV inhibitor for all-weather durability, it is strong, lightweight and economical and resistant to a wide range of chemicals for a wide range of industrial applications.

Because it is top loaded with a specially developed threaded lid and gasket, filter elements can be changed without disassembling the sump and without additional tools for tightening, requiring much less time than with many other types of filter housings.

It comes with a cone stand that supports the filter housing.

Table 11: Specifications of the filter housing.

Materials	Housing - Propylene Cone - Propylene Cartridge Plate –nitrile rubber Lid & Plate Gasket – nitrile rubber
Nominal flow	80 gpm
Maximum Pressure	90 psi
Dimensions	9.25”x11.4”x37.4”
Weight	4.5 kg
Fitting size	1.5” (side inlet/bottom outlet)
Price	$335

To speed up the water dispensing, a splitter will be connected to the cone, with two hose connections where the drinking hoses will be attached.

Table 12: Specifications of the splitter.

Materials	Zinc alloy + plastic	
Size	3.86” x 2.32” x 3.86”	
Fitting size	1-1/2”	
Price	$11	
Weight	0.21 kg	

Drinking hoses must be certified to NSF (National Sanitation Foundation) to be used to drinking water. We will use 2 drinking hoses that can be used simultaneously by a single person to increase the dispensing speed.

Table 13: Specifications of the drinking hose.

Materials	PVC	
Size	4' long x 1/2"ID	
Certified to	NSF/ANSI 372	
Price	$6	
Weight	0.21 kg	

For an easy dispensing, spray nozzles have been selected. They have a flow rate between 2.5 and 6.5 gpm that make the dispensing time very appropriate.

Table 14: Specification of the spray nozzle.

Materials	Zinc, brass and stainless steel	
Size	5” Length	
Certified to	NSF/ANSI 372	
Max pressure	100 psi	
Price	$8	
Weight	0.37 kg	

5.3 Installation and Maintenance

Set up is as simple as assembling the soft walled storage tank, connecting the pumps and water lines, assembling the filter support/distribution system and you're ready to start filling the tank with source water. With addition of the pre-dosed calcium hypochlorite in aqueous solution, the treatment tank immediately starts to disinfect the water. One hour later the water can be pumped through the cyst removal filter to the distribution lines for immediate use.

After use, the system will be cleaned, dried, inventoried, restocked and re-packed in preparation for future deployment. When not used during the year or at least annually, a training review will be provided for the response team when the system is assembled and treatment supplies are reviewed. During review, the filter, liner and expended chlorine treatment may need to be replaced to ensure the system is ready for immediate deployment. Back-up supplies will be readily available, identified or accessible when needed. Annual training supplies would cost approximately $200.

5.4 Distribution

This system can be easily transported in a mid-size car, truck, boat, rail, aircraft, and anywhere a human can drive or walk.

In a disaster relief situation, where time is of the essence, the quickest mode of transportation would be by aircraft. However, not all locations are accessible by aircraft during an emergency. That is why it is important that the system can be easily transported anywhere by road or foot. Also, the shipping case will need to be appropriate to resist the elements.

To know the storage space of the system, we have used an online software called "Easy Cargo", that let you generate volumes and load them as you want to measure spaces.

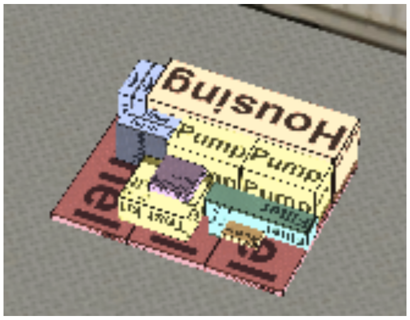


Figure 14: Components' distribution with Easy Cargo

The water system will fit in a case with the measures: 46 x 30 x 22 inches. The following shipping case has been selected:

Table 15: Specifications of the shipping case.

Materials	Plywood laminated to ABS plastic	
Measures	47.88" x 31.75" x 23.75"	
Volume	21 cubic foot	
ATA rated	ATA Spec 300	
Weight	34 kg	
Price	$900	

5.5 Technical specifications

5.5.1 Treatment technology

The water treatment consists of 3 stages: filling, disinfection and dispensing. Each one of them is carried out through different components.

Filling: water from a source is sucked through the system of hoses and hand pump, into the tank.

Disinfection: the pre-dose of calcium hypochlorite is mixed with water in a mixing container and poured into the tank as the tank is being filled.

Dispensing: water is pumped into the filter before being dispensed via two filling stations.

5.5.2 Treatment Capacities

Filling time: 30 min (300 gallons/10 gpm)

Disinfection Treatment time: 60 min

Dispense time: 60 min (2 nozzles;2.5 gpm/nozzle → 5 gpm)

Total time from filling to dispense: 130 min

Overall, we have a flow rate of 2.3 gpm → 138 gallon/h → **3300 gallons/day**

Capacity in number of people: **3300 people/day**

5.5.3 Materials and total weight

Table 16: Sizes and weights of all the components of the system.

Component	Size	Weight [kg]
Shell	8325 sq. inches	3.276 kg
12 Support panels	15”x35”x10”	8.129 kg
Liner	41”x41”x42”	4.08 kg
Pump	14.3”x 7.9”x10.24”, with 17.7” L handle	4.82 kg
3 Hoses	1.5” ID x25”	7.46 kg
Suction hose	1.5” ID x20”	3.4 kg
2 drinking hoses	4' long x 1/2"ID	0.42 kg
2 spray nozzles	5” Length	0.42 kg
Filter housing	37.4” x 11.4” ID	6.8 kg
Carbon filter	20” x 4.5” ID	3 kg
Splitter	3.86” x 2.32” x 3.86”	0.21 kg

CH tablets	-	1kg
Test kit	34.4 x 14.6 x 29.7cm	10kg
Shipping case	47.88" x 31.75" x 23.75"	34 kg
TOTAL WEIGHT		**87 kg (192 lbs)**

5.5.4 Price

Table 17: Price of all the components of the system.

Shell	$52
12 Support panels	$1704
Liner	$29
2 Pumps	$884
3 Hoses	$170.3
Suction hose	$43
2 drinking hoses	$12
2 spray nozzles	$16
Filter housing	$335
Carbon filter	$50
Splitter	$11
CH tablets	$13
Test kit	$2,000
Shipping case	$900
TOTAL PRICE	**$6220**

CHAPTER 6. CONCLUSION

To conclude, the studied system is a feasible, portable and an economic system that can help many people have quick and easy access to drinking water during emergency situations, preventing or lowering the spread of diseases through contaminated water.

Stored in 21 cubic feet of space, it only weights 192 pounds (87 kilos) and can be easily transported anywhere.

No electricity or fuel is required to power the system. Filling the tanks and final filtration is completed using hand operated pumps. However, the system can be easily fitted to power-driven pumps if necessary.

Calcium hypochlorite treatment combined with microfiltration provides the most reliable purification that meets EPA drinking water standards, inactivating bacteria, viruses and protozoa, and removing particulate, taste and odors.

The system purifies 3300 gallons of water per day (23,100 gallons per week). Purchasing 23,100 gallons of bottled water would cost $22,000 a week, without including warehousing and shipping costs. Furthermore, this amount of bottled water would weight 192,000 pounds and it would take 3,095 cubic feet of space. Thus, our system is much more economical ($6220), lighter (192 pounds) and requires far less space (21 cubic feet).

Since 1 gallons of water a day are needed for one person, one single system provides the minimum amount of clean and drinkable water to 3300 people per day.

Affordable, cost-effective and easy to use, this system can provide clean water to many people in any situation of disaster relief.

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